Scintillation Spectroscopy Measurements of Gamma-Ray Energies from the Source of $Eu^{152,154}$

Takeshi MUKOYAMA and Sakae SHIMIZU*

(Shimizu Laboratory, Institute for Chemical Research, Kyoto University)

(Received December 22, 1961)

A series of experiments empolying the NaI(Tl) scintillation spectroscopy technique was performed to determine the energies of some strong gamma rays in the decay of $Eu^{152,154}$ mixture. Various combinations of several available calibration sources were used. Many cares were taken to avoid uncertainties inherent in the measurements and to correct for non-linearlities of the system. The average gamma-ray energies measured are (122.7±1.1), (243.8±0.6), (346.2±0.7), (413.2±1.8), (581.8±1.0), (783.1±0.5), (872.6±1.1), (970.2±0.8), (1100.7±0.7), (1282.8±1.5) and (1414.2±0.7) keV. The quoted errors are the standard errors deduced from a series of measurements for each ray. These values are, in general, consistent with published values.

INTRODUCTION

Natural europium consists of two stable isotopes, Eu^{151} (44.77%) and Eu^{153} (52.23%), from which Eu^{152} and Eu^{154} are produced by means of (n,γ) reactions. In many cases Eu^{152} and Eu^{154} are obtainable as a mixture because of difficulty of the separation. Eu^{152} decays with a half life of about 13 years either by electron emission to Gd^{152} or by K-capture and weak positron emission to Sm^{152}, while Eu^{154} emitts electrons only leading to Gd^{154} with a half life of about 16 years. Gamma-ray energies from pure Eu^{152} and Eu^{154} have been measured considerably in detail by many workers. Those from the long-lived $Eu^{152,154}$ mixture have also been reported by several authors, but some uncertainties seem to remain.

The present work was undertaken to determine energies of some of gamma rays from the $Eu^{152,154}$ mixture as precise as possible by measuring NaI(Tl) scintillation pulses by the use of a 256-channel pulse-height analyzer as well as of some other gamma-ray emitters as calibration sources. The photon energies from some of the calibration sources have already been determined precisely by other workers, however, several gamma-ray energies used had to be determined by the present authors.

The determinations were performed by comparing the scintillation pulse-height distributions induced in the NaI(Tl) crystal by the gamma rays to be measured with those of calibration gamma rays of known energies. The unknown values were measured by assuming the response of the scintillator to be linear over the energy region covering the unknown and the nearest calibration ener-

* 向山 毅, 清水 栄

gies. Eu^{152} and Eu^{154}, having very complicated decay schemes, are known to emit many gamma rays of different energies, however, in the present set of experiments we have determined the energies of eleven lines with reasonable standard errors.

EXPERIMENTAL METHOD

Gamma-ray energies determined by the scintillation method suffer from inherent uncertainties produced by electric and phototube gain shifts, pulse-height analyzer zero shifts, scattering effect and a broad resolution. The poor resolution seems to prevent an accuracy, especially when the observed spectra about the peaks are not exactly symmetrical. Great cares should be taken to reduce such uncertainties to minimum as far as possible.

Gamma-ray spectra were measured using a 3 inch diameter by 3 inch long NaI(Tl) crystal mounted on a DuMont 6363 photomultiplier tube. The output pluses from this scintillation probe were fed to a slightly modified Argonne-type 256-channel pulse-height analyzer via a cathode-follower amplifier.

The $Eu^{152,154}$ source of about 40 μC was prepared by evapolating a drop of

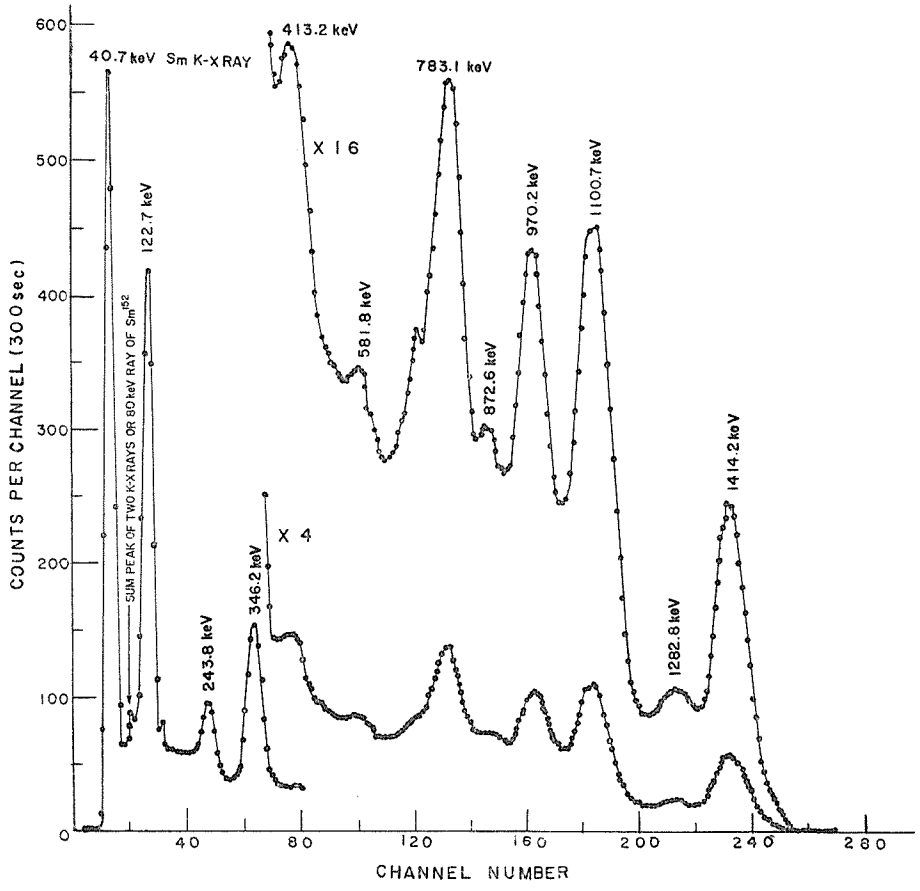

Fig. 1. Full scintillation spectrum of gamma rays from the $Eu^{152,154}$ mixture.

$EuCl_3$ in HCl solution, 79.4% Eu^{152} and 20.6% Eu^{154}, obtained from the Radiochemical Centre in Amersham, England. The evapolated deposit of about 3 mm diameter was sealed in a small polystyrene pan. All the other sources were prepared in the same way. The NaI(Tl) scintillation probe was mounted vertically in the middle of the experimental room by the tripod and all sources used in the present work were always placed 25 cm just above the scintillation crystal. Some precautions were also taken to minimize the scattered radiation from neighboring bodies which may distort the gamma-ray spectrum. The observed full spectrum of the gamma-rays from the $Eu^{152,154}$ mixture is shown in Fig. 1.

To avoid systematic errors in the present work many combinations of calibration sources were used. The calibration lines of gamma rays with precisely determined energies from the gamma-ray emitters available in the present experiment are listed in Table 1. Since energies of five lines among those listed were so far not determined precisely with good standard errors, we determined the energies of these five gamma rays by the procedures described in the following pages and shown in Table 2.

Table 1. Energies of calibration gamma rays.

No.	Source	Energy (keV)	References
1	$Sb^{125}(Te^{125m})$	35.2 ±0.3	der Matheosian and McKeown[1]
2	Tm^{170}	84.2 ±0.3	der Matheosian and McKeown[1]
3	Sb^{125}	174.7 ±0.4	der Matheosian and McKeown[1]
4	Sb^{125}	428.6 ±0.6	present work**
5	m_e*	510.976±0.007	DuMond and Cohen[2]
6	Sb^{125}	601.7 ±0.9	present work**
7	Ag^{110m}	655.9 ±0.9	present work**
8	Cs^{137}	661.6 ±0.2	Way *et al.*[3]
9	Ag^{110m}	886.0 ±0.9	present work**
10	Zn^{65}	1119.6 ±1.1	present work**
11	Co^{60}	1172.8 ±0.5	Lindström *et al.*[4]
12	Na^{22}	1275.0 ±0.5	Ajzenberg and Lauritsen[5]
13	Co^{60}	1332.5 ±0.3	Lindström *et al.*[4]

* Annihilation radiation

** The determination method is described in the following pages.

To diminish the count-rate drifts which depend upon the average phototube anode current the lowest possible gain was used, and to eliminate the effect of the residual drift the gamma rays from the unknown and calibration sources were superposed in the same spectrum. If the calibration source has a peak in the vicinity of the measured peak, a subtraction was performed using a spectrum of the interfering gamma rays measured with the source in the same position it occupied during the combined run. The examples obtained in the cases of gamma rays from Sb^{125}, Zn^{65} and Ag^{110m} are shown in Fig. 2.

Fig. 3 shows two typical spectra near the peaks used in determination of the channel number of the peaks. Straight lines were drawn on the both sides of

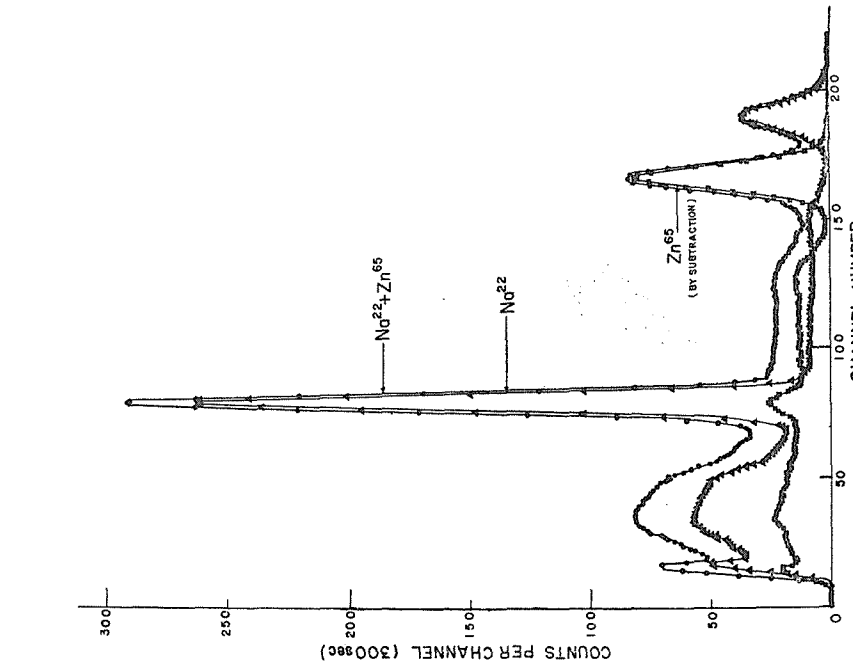
COUNTS PER CHANNEL (300sec)
CHANNEL NUMBER
$Na^{22}+Zn^{65}$
Na^{22}
Zn^{65}
(BY SUBTRACTION)

Fig. 2(b).

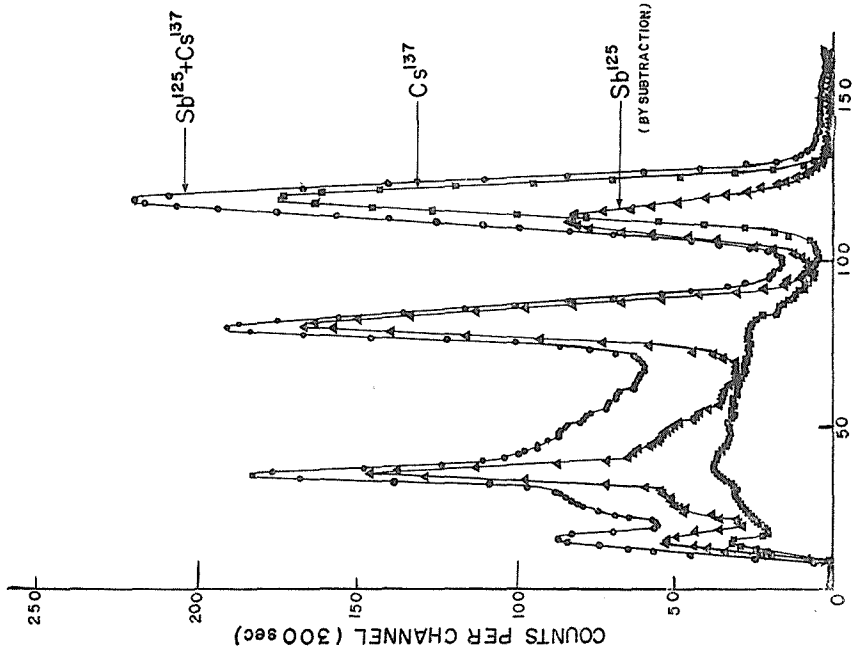
COUNTS PER CHANNEL (300 sec)
CHANNEL NUMBER
$Sb^{125}+Cs^{137}$
Cs^{137}
Sb^{125}
(BY SUBTRACTION)

Fig. 2(a).

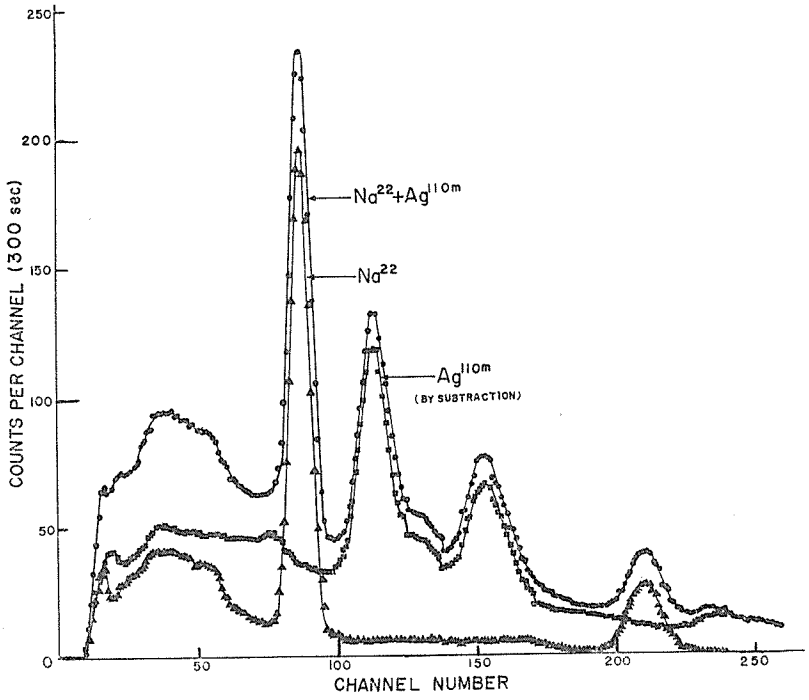

Fig. 2(c).

Fig. 2. Examples of subtraction of interfering gamma rays and separation of photopeaks.

(a) Separation of Cs^{137} 0.66 MeV line from a combination of Cs^{137} and Sb^{125}.

(b) Separation of Na^{22} 1.28 MeV line and annihilation peak from a combination of Na^{22} and Zn^{65}.

(c) Separation of Na^{22} 1.28 MeV line and annihilation peak from a comination of Na^{22} and Ag^{110m}.

the peaks as shown in Fig. 3. If the slopes of both lines were exactly opposite, the position of the peak was determined from the channel number of their intersection, and the standard error was estimated from the scatter of the experimental points about the lines. When the peak was asymmetric, the peak position was taken as the average of the channel numbers at which the count rates attained about two thirds of its maximum value.

The deviation from linearity of the pulse-height analyzer was corrected by using a pulse generator. The observed channel numbers were plotted as a function of pulse generator outputs and an arbitrary straight line was drawn near the observed points, as shown in Fig. 4. The correction for each peak channel number was determined at the obtained peak channel as the difference between the readings of the corresponding pulse generator output and the arbitrary straight line drawn in Fig. 4. The standard error assigned to each non-linearity correction was estimated by assuming an uncertainty in each input voltage to be ± 0.1 channel. Residual non-linearities and systematic line shape-difficulties, occur in both lower and upper part of the channel number, can be excluded by carring out the measurements in the middle part of the non-linearity

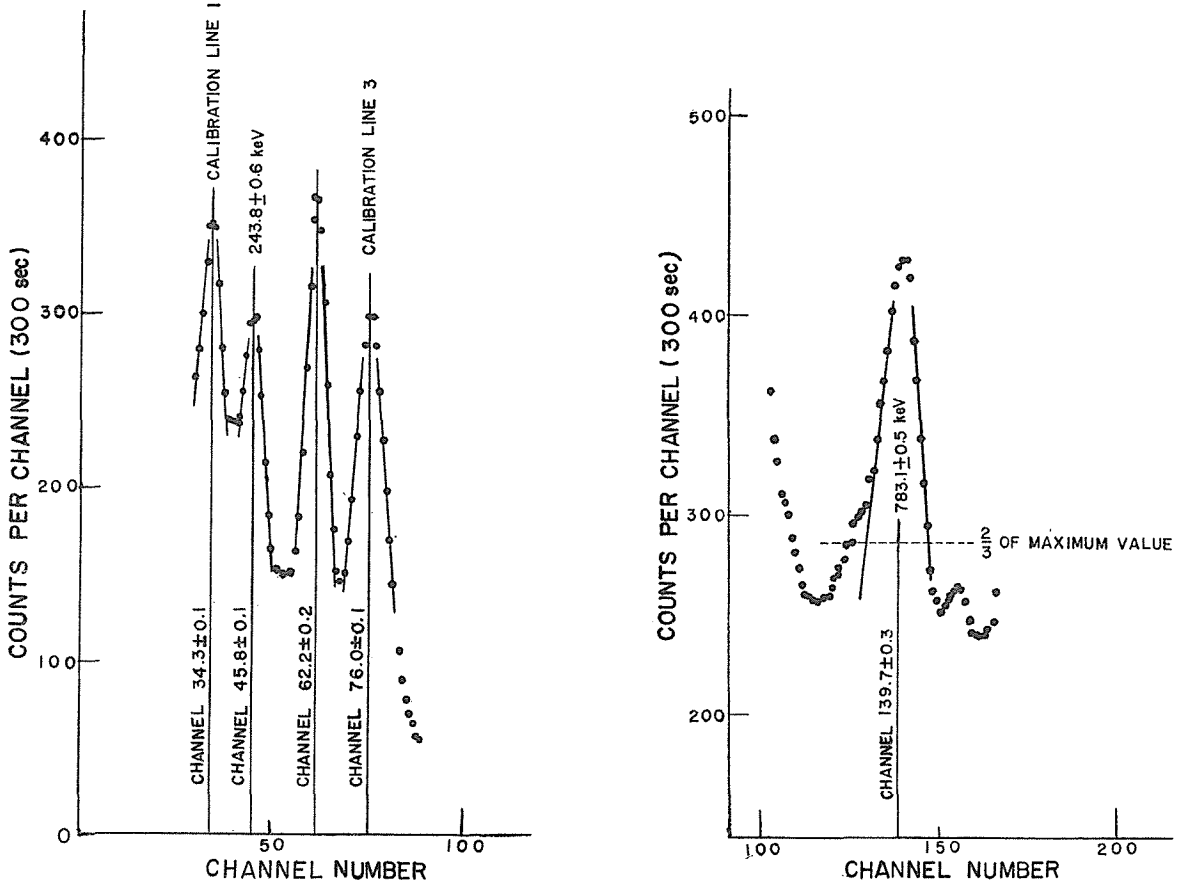

Fig. 3. Two typical examples of determination of positions of photopeaks.

(a) Two lines drawn on the both sides of the peaks have just opposite slopes. Data are taken from an experiment using calibration source, 1 and 3, for determining the position of the 243.8±0.6 keV peak.

(b) The case when an observed peak is not symmetric. The peak is determined to be 783.1±0.5 keV using calibration sources, 5 and 12.

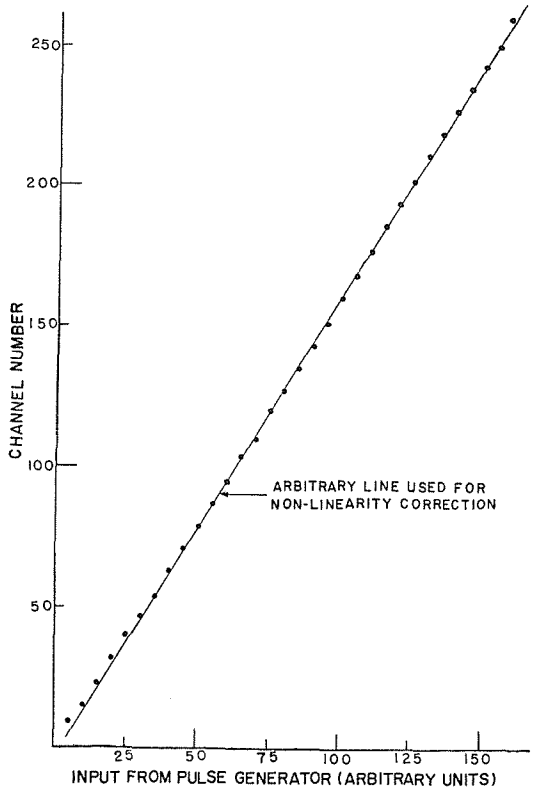

Fig. 4. Pulse generator response curve using for non-linearity corrections.

correction curve, 50 to 200 channel, by means of adjusting a gain of the phototube as far as possible.

The peak energies were estimated by the 1st order interpolation method between two nearest calibration lines, however, in a few cases, especially for the 1.4 MeV line of $Eu^{152,154}$, extrapolations were performed.

As the first step, from the precisely known energies of the standard lines of some gamma-ray emitters we had to determine accurately the energies of five lines, which were used also as the calibration rays, listed in Table 1.

The energy for the unknown gamma ray was obtained by the following formula:

$$E = E_1 + g(C - C_1), \tag{1}$$

where E = unknown gamma-ray energy (keV),
C = channel number for the E peak,
g = conversion gain (keV·ch^{-1}) between the calibration lines,
$= (E_2 - E_1)/(C_2 - C_1)$,
E_1, E_2 = energies used for calibration lines,
and C_1, C_2 = channel numbers for the E_1 and E_2 peaks, respectively.

Using interpolation functions $f_1 = (C - C_1)/(C_2 - C_1)$ and $f_2 = (C_2 - C)/(C_2 - C_1) = 1 - f_1$, E can be written as

Table 2. Determination of five gamma-ray energies used as calibrations.

Nuclide	Standard source	Standard energy (keV)	Peak channel of standard	Non-linearity correction	Corrected peak of standard	Peak channel	Non-linearity correction	Corrected peak channel	Determined energy (keV)
Sb^{125}	Sb^{125}	174.7 ±0.4	36.4±0.1	−1.3±0.2	35.1±0.2	78.3±0.1	−0.1±0.1	78.2±0.1	428.6±0.6
	Cs^{137}	661.6 ±0.2	117.6±0.1	0.2±0.1	117.8±0.1				
Sb^{125}	Sb^{125}	174.7 ±0.4	36.4±0.1	−1.3±0.2	35.1±0.2	107.4±0.1	0.2±0.1	107.6±0.1	601.7±0.9
	Cs^{137}	661.6 ±0.2	117.6±0.1	0.2±0.1	117.8±0.1				
Ag^{110m}	m_e	510.976±0.007	88.4±0.1	−0.1±0.1	88.3±0.1	110.8±0.1	0.1±0.1	110.9±0.1	655.9±0.9
	Na^{22}	1275.0 ±0.5	208.0±0.1	−0.5±0.2	207.5±0.2				
Ag^{110m}	m_e	510.976±0.007	88.4±0.1	−0.1±0.1	88.3±0.1	146.6±0.1	0.2±0.1	146.8±0.2	886.0±0.9
	Na^{22}	1275.0 ±0.5	208.0±0.1	−0.5±0.2	207.5±0.2				
Zn^{65}	m_e	510.976±0.007	79.5±0.1	−0.1±0.1	79.4±0.1	167.5±0.1	0.1±0.1	167.6±0.1	1119.6±1.1
	Na^{22}	1275.0 ±0.5	190.3±0.1	−0.2±0.2	190.1±0.2				

$$E=f_2E_1+f_1E_2, \tag{2}$$

and then error in E is

$$\varepsilon^2=f_2^2\varepsilon_1^2+f_1^2\varepsilon_2^2+g^2(\gamma^2+f_2^2\gamma_1^2+f_1^2\gamma_2^2), \tag{3}$$

where ε=error in E,

ε_1, ε_2=errors in E_1 and E_2, respectively,

γ=error in C,

and γ_1, γ_2=errors in C_1 and C_2, respectively.

By this interporation method energies of five calibration lines were determined; the results are shown in Table 2.

In the present work, for eleven lines of gamma rays from the $Eu^{152,154}$ mixture the energy determination by such interporation method was applied by using

Table 3. Gamma-ray energies determined by a series of experiments.

Observed peak (MeV)	Couple of calibration lines*	Determined energy (keV)	Observed peak (MeV)	Couple of calibration lines*	Determined energy (keV)
0.12	1,3	123.8±0.5		5,10	782.2±1.4
	2,8	121.7±1.2		8,12	782.2±1.2
0.24	3,8	243.1±1.2	0.87	5,12	870.3±2.5
	3,5	244.3±1.2		6,12	872.1±2.6
	3,6	244.4±1.2		4,10	875.9±2.1
	3,7	242.0±1.3		8,12	871.9±1.5
	3,9	243.0±1.3	0.97	8,10	969.2±2.2
	2,8	245.8±1.2		5,12	971.2±1.7
0.34	3,4	346.4±1.5		5,11	968.0±1.3
	3,6	344.6±1.1		4,10	973.7±2.2
	3,7	347.8±1.5		5,10	968.2±1.6
	2,8	346.8±1.2		5,13	971.9±1.2
0.41	3,7	411.5±2.0	1.11	5,12	1102.2±2.3
	3,9	415.0±2.1		6,12	1100.7±1.0
0.58	3,9	582.8±1.5		5,10	1102.5±1.8
	4,10	583.1±1.5		8,12	1099.7±1.5
	4,11	579.4±2.1		11,13	1098.9±2.1
	4,13	579.4±2.1	1.28	8,11	1287.8±2.8
0.78	8,10	779.8±2.0		5,10	1281.7±2.5
	5,12	781.8±2.5		11,13	1281.9±1.4
	6,12	783.0±2.1	1.41	5,12	1413.7±1.7
	3,9	785.3±1.2		5,10	1417.9±2.2
	4,9	782.4±1.1		8,12	1415.5±2.0
	5,9	782.8±1.3		11,13	1414.2±1.2
	4,10	783.7±1.5		9,13	1413.2±1.6
	4,11	785.7±2.1		9,11	1411.5±2.3
	4,13	785.7±2.1			

* Numbers in this column represent the calibration gamma rays shown in Table 1.

various combinations of a couple of calibration lines as listed in Table 3. From the values obtained by different combinations of calibration lines the weighted mean value, $\bar{E}$, as the most reliable one for each gamma ray was calculated by the following procedure. The weight was taken as inversely proportional to the square of the estimated standard error in each $\bar{E}$.

Suppose that $E_n \pm \varepsilon_n$ = energy and error obtained from Eqs. 2 and 3,

$W_n \equiv 1/\varepsilon_n^2$ = weight assigned to E_n,

and $\bar{E} \pm \sigma_i(\bar{E})$ = output value and error of an unknown gamma ray,

$\bar{E}$ and $\sigma_i(\bar{E})$ were determined by the following relations:

$$\bar{E} = \frac{\sum_n W_n E_n}{\sum_n W_n}, \qquad n = 1, 2, 3, \cdots\cdots, N, \tag{4}$$

and

$$\sigma_i^2(\bar{E}) = \frac{\sum_n W_n^2 \varepsilon_n^2}{(\sum_n W_n)^2} = \frac{1}{\sum_n W_n}, \tag{5}$$

where N represents number of experiments performed for the peak to be measured with different couples of calibration lines. The standard error estimated from Eq. 5 is a function of what is called the internal consistency of the observations. The another expression of the error which depends upon the external consistency is

$$\sigma_e^2(\bar{E}) = \frac{\sum_n W_n (E_n - \bar{E})^2}{(N-1)\sum_n W_n}, \tag{6}$$

The statistical test for goodness of fit of data was carried out by calculating the ratio

$$R = \frac{\sigma_e(\bar{E})}{\sigma_i(\bar{E})} = \left\{ \frac{\sum_n W_n (E_n - \bar{E})}{N-1} \right\}^{1/2}, \tag{7}$$

and checking whether it was unity within a standard error $1/[2(N-1)]^{1/2}$. When it is so, the obtained value $\bar{E}$ is consistent and then the larger of the values of $\sigma_i(\bar{E})$ and $\sigma_e(\bar{E})$ can be chosen as the standard error of the weighted mean being the final value to be obtained.

RESULT AND DISCUSSION

The final result of energy determination of eleven gamma rays from the $Eu^{152,154}$ mixture is given in Table 4, in comparison with some values which have been published by other workers. The values thus determined are assigned to the peaks we observed as shown in Fig. 1. Since both Eu^{152} and Eu^{154} decay in very complicated modes with emission of many gamma rays of different energies and some of which are known very near in energy, by the present work without any β-γ coincidence measurement we could not deduce the isotope assignment for each gamma ray.

The observed peak with the lowest energy was estimated to be 40.7 ± 0.5 keV by the use of the calibration lines of 35.2 keV (Te^{125m}) and 174.7 keV (Sb^{125}).

Table 4. Determined energies of eleven gamma rays from the source of $Eu^{152,154}$.

Present work (keV)	Other works* (keV)	Other works' method**	References
122.7±1.1	123 + 2 (a + b)	s, ce, pe	Shull[6]
	121.8 + 0.5 (a)	sπ, ce	Church and Goldhaber[7]
	121.2 + 0.3 (a) 122.4 + 0.3 (b)	sπ, ce	Lee and Katz[8]
	121.77+ 0.12(a) 123.07+ 0.12(b)	sd, ce	Bobykin and Novik[9]
	122.2 + 0.2 (a) 123.1 + 0.2 (b)	scin, sπ, ce	Cork *et al.*[10]
	124 + 4 (a)	scin	Bhattacherjee and Raman[11]
	122 + 1 (a) 123 + 1 (b)	s, ce	Nathan and Waggoner[12]
	121 + 2 (a)	sl, ce	Bhattacherjee *et al.*[13]
243.8±0.6	244 ± 2 (a − b)	s, ce, pe	Shull[6]
	244.3 ± 0.5 (a) 247.7 ± 0.5 (b)	sπ, ce	Church and Goldhaber[7]
	243.6 ± 0.7 (a)	sπ, ce	Lee and Katz[8]
	244.66± 0.24(a) 248.04± 0.25(b)	sπ, ce	Bobykin and Novik[9]
	245.3 ± 0.5 (a) 248.3 ± 0.5 (b)	scin, sπ, ce	Cork *et al.*[10]
	244 ± 7 (a)	scin	Bhattacherjee and Raman[11]
	244 ± 2 (a)	s, ce	Nathan and Waggoner[12]
	244 ± 4 (a)	sl, ce	Bhattacherjee *et al.*[13]
346.2±0.7	343.9 ± 2.0 (a + b)	s, ce, pe	Shull[6]
	344.2 ± 1.0 (a)	sπ, ce	Lee and Katz[8]
	344.32± 0.34(b)	sd, ce	Bobykin and Novik[9]
	345.1 ± 0.7 (a)	scin, sπ, ce	Cork *et al.*[10]
	340 ±10 (a)	scin	Bhattacherjee and Raman[11]
	344 ± 3 (a)	s, ce	Nathan and Waggoner[12]
	344 ± 7 (a)	sl, ce	Bhattacherjee *et al.*[13]
413.2±1.8	412.3 ± 2.0 (a + b)	s, ce, pe	Shull[6]
	411.23± 0.82(b)	sd, ce	Bobykin and Novik[9]
	412.2 ± 0.8 (a)	scin, sπ, ce	Cork *et al.*[10]
	410 ±20 (a)	scin	Bhattacherjee and Raman[11]
	420 ± 4 (a)	s, ce	Nathan and Waggoner[12]
	410 ± 8 (a)	sl, ce	Bhattacherjee *et al.*[13]
581.8±1.0	583.1 ± 0.6 (a)or(b)	sd, ce	Bobykin and Novik[9]
	585.8 ± 1.2 (a)	scin, sπ, ce	Cork *et al.*[10]
	585 ±12 (b)	sl, ce	Bhattacherjee *et al.*[14]
783.1±0.5	772 ± 2 (a + b)	s, ce, pe	Shull[6]
	779.5 ± 0.8 (b)	sd, ce	Bobykin and Novik[9]
	782.0 ± 1.6 (a)	scin sπ, ce	Cork *et al.*[10]
	770 ±22 (a)	scin	Bhattacherjee and Raman[11]
	775 ± 8 (a)	s, ce	Nathan and Waggoner[12]
	770 ±15 (a)	sl, ce	Bhattacherjee *et al.*[13]

Table 4. (*continued*)

Present work (keV)	Other works* (keV)	Other works' method**	References
	868.5 ± 0.9 (a) 873.7 ± 0.9 (b)	sd, ce	Bobykin and Novik[9]
872.6±1.1	872 ± 2 (a) 875 ± 2 (b)	scin, sπ, ce	Cork *et al.*[10]
	870 ±30 (a)	scin	Bhattacherjee and Raman[11]
	860 ± 9 (a)	s, ce	Nathan and Waggoner[12]
	870 ±17 (a)	sl, ce	Bhattacherjee *et al.*[13]
	959 ± 2 (a + b)	s, ce, pe	Shull[6]
	964.8 ± 1.0 (a) 996.9 ± 1.0 (b) 1005.4 ± 1.0 (b)	sd, ce	Bobykin and Novik[9]
970.2±0.8	969 ± 2 (a) 999 ± 2 (b)	scin, sπ, ce	Cork *et al.*[10]
	970 ±20 (a)	scin	Bhattacherjee and Raman[11]
	965 ±10 (a)	s, ce	Nathan and Waggoner[12]
	970 ±19 (a)	sl, ce	Bhattacherjee *et al.*[13]
	1082 ± 2 (a + b)	sπ, ce	Shull[6]
	1086.6 ± 1.1 (a) 1112.7 ± 1.1 (a)	sd, ce	Bobykin and Novik[9]
1100.7±0.7	1100 ±22 (a) 1188 ±22 (a)	scin, sπ, ce	Cork *et al.*[10]
	1090 ±21 (a)	scin	Bhattacherjee and Raman[11]
	1090 ±11 (a)	s, ce	Nathan and Waggoner[12]
	1090 ±22 (a)	sl, ce	Bhattacherjee *et al.*[13]
	1272.7 ± 1.3 (a) 1276.0 ± 1.3 (b)	sd, ce	Bobykin and Novik[9]
	1281 ±26 (b)	scin, sπ, ce	Cork *et al.*[10]
1282.8±1.5	1260 ±40 (a)	scin	Bhattacherjee and Raman[11]
	1280 ±13 (b)	s, ce	Nathan and Waggoner[12]
	1285 ±25 (b)	sl, ce	Bhattacherjee *et al.*[14]
	1402 ± 2 (a + b)	s, ce, pe	Shull[6]
	1409.4 ± 1.4 (a)	sd, ce	Bobykin and Novik[9]
	1416 ±28 (a)	scin, sπ, ce	Cork *et al.*[10]
1414.2±0.7	1410 ±25 (a + b)	scin	Bhattacherjee and Raman[11]
	1415 ±14 (a)	s, ce	Nathan and Waggoner[12]
	1410 ±28 (a)	sl, ce	Bhattacherjee *et al.*[13]

* (a)=gamma rays emitted from Eu^{152}; (b)=gamma rays emitted from Eu^{154}.

** Abbreviations used: s=magnetic beta-ray spectrometer; sl=short magnetic lens beta-ray spectrometer; sπ=180° focusing beta-ray spectrometer; sd=double focusing beta-ray spectrometer; scin=scintillation spectrometer; ce=internal conversion electrons measured; pe=photoelectrons measured (external conversion).

This line could be established to be due to the K-X ray from Sm^{152}, in good agreement with a published value, 41.01 keV.[15] The second small peak may be due to the sum peak of two K-X rays or to the 80 ± 4 keV gamma ray of Sm^{154} [11] and a small peak neighbouring the 122.7 keV peak may be also due to the sum peak of this K-X ray and the 122.7 keV ray. The small peak having nearly 700 keV was too weak to determine its energy precisely by our measurements.

Some uncertainties of the gamma-ray energy determination by the scintillation spectroscopy are hardly avoidable, but resonably good results can be obtained if sufficient cares are taken and proper corrections are made. The major avoidable sources of the error are asymmetry in scattering and spatial distribution of the source as well as uncertainties inherent in the non-linearity corrections and long-range interpolation or extrapolation as discussed in the preceding section. However, the last factor may be diminished by the use of many suitable calibration sources.

REFERENCES

(1) E. der Matheorsian and M. McKeown, *BNL*-605, Brookhaven National Laboratory (1960).
(2) J. W. M. DuMond and E. R. Cohen, *Rev. Mod. Phys.*, **25**, 681 (1953).
(3) K. Way *et al.*, Nuclear Data Sheets, NRC 58-2-66, National Academy of Sciences, National Research Council, Washington D. C.
(4) G. Lindström, A. Hedgran and D. E. Alburger, *Phys. Rev.*, **89**, 1303 (1953).
(5) F. Ajzenberg and T. Lauritsen, *Rev. Mod. Phys.*, **27**, 77 (1955).
(6) F. B. Shull, *Phys. Rev.*, **74**, 917 (1948).
(7) E. L. Church and M. Goldhaber, *Phys. Rev.*, **95**, 626A (1954).
(8) M. R. Lee and R. Katz, *Phys. Rev.*, **93**, 155 (1954).
(9) B. V. Bobykin and K. M. Novik, *Dokl. Akad. nauk SSSR*, **115**, 263 (1957); *Soviet Phys. Doklady*, **2**, 322 (1958).
(10) J. M. Cork, M. K. Brice, R. G. Helmer and D. E. Sarason, *Phys. Rev.*, **107**, 1621 (1957).
(11) S. K. Bhattacherjee and S. Raman, *Nuclear Physics*, **4**, 44 (1957).
(12) O. Nathan and M. A. Waggoner, *Nuclear Physics*, **2**, 548 (1956/57).
(13) S. K. Bhattacherjee, T. D. Nainan, S. Raman and B. Sahai, *Nuovo cimento*, **7**, 501 (1958).
(14) S. K. Bhattacherjee, S. Raman and S. K. Mitra, *Proc. Indian Acad. Sci.*, A47, 295 (1958).
(15) G. J. Nijgh, A. H. Wapstra and R. van Lieshout, "Nuclear Spectroscopy Tables" (North-Holland Publishing Company, Amsterdam, 1959) Chap. 7, p. 81.